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DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150675

OUTDOOR THERMAL EFFICIENCY EVALUATION OF THE YING SOLAR COLLECTOR

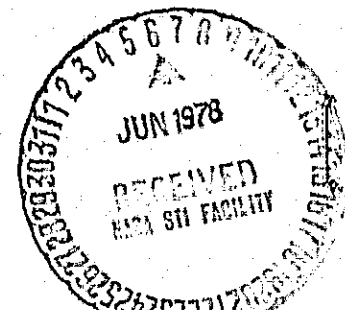
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For the U. S. Department of Energy



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Solar Energy

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16. ABSTRACT This report contains the procedures used and the results obtained during the evaluation test program on the Ying Manufacturing Corporation, Model SP4120, Solar Collector. The flat-plate collector uses water/prestone anti-freeze solution as the working fluid. The absorber plate is aluminum with 1/2 inch diameter stainless steel tubing. The glazing consists of double, UV stabilized G. E. Lexan. The collector weight is 105 pounds with overall external dimensions of approximately 50" x 146" x 5 inches. This collector had previously been used in weather exposure evaluation at the Marshall Space Flight Center solar test facility.					
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SUMMARY

Thermal efficiency tests were conducted on a Ying collector which previously was used in weather exposure evaluations. The tested collector had experienced visible deterioration of the absorber coating material in the weather exposure evaluation. The weather exposure evaluation was conducted on the Marshall Space Flight Center Solar Facility Test Bed #4 during the period between June 1, 1977, and August 26, 1977.

It was mutually agreed between IBM and Wyle that thermal efficiency evaluations would be conducted on the subject collector and that the incident angle modifier and thermal response tests were not required. Complete thermal performance tests were not justified since the collector was not designated as part of the IBM field test demonstration systems. Results of thermal efficiency evaluations are shown graphically in Figures 2 and 3.

2.0

PURPOSE

The purpose of this report is to present the test procedures used and the test results obtained during an evaluation test program. The test program was conducted to obtain thermal efficiency performance data on a Ying double-covered solar collector under outdoor conditions. These tests were conducted at the Marshall Space Flight Center Solar Heating and Cooling Test Facility Test Bed #4. Thermal efficiency tests were conducted and data were evaluated according to methods of Reference 2.1.

3.0

REFERENCES

3.1

ASHRAE-93-77

Method of Testing to Determine the
Thermal Performance of Solar Collectors

4.0

COLLECTOR DESCRIPTION

Manufacturer: Ying Manufacturing Corp.

Manufacturer's Address: Gardena, California

Model Number: SP4120

Serial Number: N/A

Type: Flat plate

Working Fluid: 50% by volume water/Prestone antifreeze
solution

Gross Collector Area, ft²: 50.35

COLLECTOR DESCRIPTION (Continued)

Overall external dimensions:

Width, inches: 49.75
Length, inches: 145.75
Thickness, inches: 4.95
Aperture area,
ft²: 46.67

Collector glazing:

Double, UV stabilized G.E. Lexan (.010" thick)

Absorber Plate:

Aluminum plate mechanically attached to 1/2" diameter stainless steel tubes spaced 5.3 inch centers. The absorber coating is Dunn Edwards W201-20 Flat Black Coating ($\alpha = .93$, $\epsilon = 0.9$).

Weight, lbs:

Full: 115
Empty: 105

Manufacturer's Assembly Drawing:

Manufacturer's drawing not available.

5.0 TEST CONDITIONS AND TEST EQUIPMENT

5.1 Ambient Conditions

Thermal performance tests were conducted in the existing natural environment at the MSFC Solar Heating and Cooling Test Facility.

5.2 Instrumentation and Equipment

Test equipment used in the performance of this test program comply with the requirements of MSFC-MMI-5300.4C, Metrology and Calibration. Instrumentation locations on the test loop and the collector are depicted in Figure 1. A description of the equipment used in the test program is provided below.

<u>Apparatus</u>	<u>Manufacturer/Model</u>	<u>Range/Accuracy</u>
Platinum Resistance Thermometer	Supplied by Collector Manufacturer	0-300°F ± 0.5°F
Pyranometer	Eppley - PSP	0-800 BTU/Ft ² ·Hr ± 3%
Liquid Loop	MSFC Supplied	.1 - 1.3 GPM
Directional Anemometer	Supplied by AMC	0 - 30 MPH
Flow Meter	Foxboro/1/2-2 81T3C1	.1 - .91 ± 1% GPM
Platinum Resistance Thermometer	Hy-Cal	0-500°F ± 0.5°F
Differential Pressure Transducer	Statham	0 - 10 PSID ± 1%

All transducers with the exception of the Eppley PSP pyranometer used in recording test data are calibrated by either NASA or AMC calibration laboratories as required by MSFC MMI 5300.4C. The PSP pyranometer was calibrated by the manufacturer. The stated accuracy of individual transducers reflects the overall expected accuracy through the data acquisition system.

5.3 Data Systems

Test data obtained during tests were transmitted from the test site through primary data acquisition system #1 to the real time data link and the DDP-224 computer located in Building 4646. A separate data link between Building 4646 and the test site provides for printout of real time data at the test site.

5.0 TEST CONDITIONS AND TEST EQUIPMENT (Continued)

5.3 Data Systems (Continued)

The end-to-end accuracy of data derived from system testing is subject to an error analysis which accounts for all inaccuracies in the transducer signal conditioning, signal transmission and computer processing methods. Since a formal systems error analysis will not be done, confidence in printout accuracies was established by installing calibrated "parallel" transducers and direct readouts at key points in the system and performing comparison checks from time to time before, during and after tests. The results of such checks together with a review of the data for anomalies will indicate that the data presented is suitable for the purpose intended.

6.0 TEST REQUIREMENTS AND PROCEDURES

6.1 Collector Thermal Efficiency Test

Tested By Burt Henderson
Started February 20, 1978
Completed March 6, 1978

6.1.1 Requirements

Utilizing the MSFC portable liquid loop, parametric performance evaluation data shall be recorded of the following test variables and conditions. The heat transfer fluid will consist of a 50% by volume solution of Prestone antifreeze and water.

<u>Variable/Condition</u>	<u>Requirement</u>
(1) Collector inlet liquid temperature differential above existing ambient temperature level	At least four different values of inlet temperature to obtain $\left(\frac{\Delta T}{I}\right)$ in the range of 0.1 to 0.4.
(2) Collector outlet liquid temperature	Measured data
(3) Incident solar flux level	Greater than 200 BTU/Hr·Ft ² °F
(4) Liquid flow rate through the collector	380 and 680 lbm/hr·ft ²
(5) Wind speed	Less than 10 MPH
(6) Ambient air temperature	The range of ambient air temperatures for all tests shall not exceed 54°F.

6.1.2 Procedure

1. Mount test specimen on the test support at a 45° angle with reference to the horizontal.
2. Assure that the solar insolation angle is within $\pm 15^\circ$ of the collector normal at initiation of tests.
3. Insulate all liquid lines.
4. Connect instrumentation leads to data acquisition system in accordance with Table I.

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.1 Collector Thermal Efficiency Test (Continued)

6.1.2 Procedure (Continued)

5. Assure that data acquisition system is operational.
6. Perform sensor accuracy verification tests.
7. Start liquid flow loop and establish the required flow rate.
8. Establish the required inlet temperature.
9. Record data for a minimum of five minutes at these stabilized conditions.
10. Repeat Steps 7 th. ough 10 as necessary to complete all the required test conditions with independent tests to cover the range of the test parameter $\left[\frac{T_{i,f} - T_a}{I} \right]$ from 0.1 to 0.4.
11. Upon completion of testing, power down the liquid loop.
12. Inform data control group that operation has terminated. (A)

6.1.3 Results

The data obtained during thermal efficiency testing are presented in Tables I and II. Analyses were performed using this test data to determine the collector thermal efficiency according to the methods of Reference 1. Thermal efficiency of the collector is plotted in Figures 2 and 3 versus the test parameter $\left[\frac{T_{i,f} - T_a}{I} \right]$ for the two fluid flow rates.

Thermal Performance Test

The analysis of data contained in this report is in accordance with the National Bureau of Standards recommended approach. This approach is outlined below.

The efficiency of a collector is stated as:

$$\eta_c = \frac{q_u/A}{I} = \frac{\dot{m} C_{tf} (T_{f,e} - T_{f,i})}{I} \quad (1)$$

where:

q_u : rate of useful energy extracted from the Solar Collector (BTU/Hr)

A : Gross collector area (Ft²)

I : Total solar energy incident upon the plane of the solar collector per unit time per unit area (BTU/Hr·Ft²)

$\dot{m}$: Mass flow rate of the transfer fluid through the collector per unit area of the collector (lbm/Ft²·Hr)

C_{tf} : Specific heat of the transfer fluid (BTU/lb·°F)

$T_{f,e}$: Temperature of the transfer fluid leaving the collector (°F)

$T_{f,i}$: Temperature of the transfer fluid entering the collector (°F)

Rewriting Equation (1) in terms of the total collector area yield:

$$\eta_c = \frac{(\dot{m}A) C_{tf} (T_{f,e} - T_{f,i})}{(IA)} = \frac{\dot{M} C_{tf} (T_{f,e} - T_{f,i})}{P_i} \quad (2)$$

Notice that:

$P_i = IA$: Total Power Incident on the Collector.

$\dot{m}A = \dot{M}$: Total Mass Flow Rate through the Collector.

Therefore $\dot{M} C_{tf} (T_{f,e} - T_{f,i})$ = Total Power Collected by the Collector.

7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

Substitution in Equation (2) results in:

$$\eta_c = \frac{P_{abs}}{P_{inc}} \quad (3)$$

where:

P_{abs} = Total collected power

P_{inc} = Total incident power

This value of efficiency is expressed as a percentage by multiplying by 100. This expression for percent efficiency is:

$$\text{Collector Efficiency} = \frac{P_{abs}}{P_{inc}} \times 100 \quad (4)$$

or from Equation (2), collector efficiency is defined by the equation:

$$\eta_c = \frac{\dot{M} C_{p,f} (T_{f,e} - T_{f,i})}{P_i} \times 100 \quad (5)$$

Each term in Equation (5) was measured and recorded independently during the test. The calculated values of efficiency were determined at sixty-second intervals. The mean value of efficiency was determined over a five-minute period during which the test conditions remained in a quasi-steady state. Each five-minute period constitutes one "data point" as is graphically depicted on a plot of percent efficiency versus

$$\left((T_i - T_a) / I \right)$$

where:

T_i = Fluid inlet temperature ($^{\circ}\text{F}$)

T_a = Ambient temperature ($^{\circ}\text{F}$)

I = Incident flux per unit area ($\text{BTU}/\text{Hr} \cdot \text{ft}^2$)

The abscissa term $\left((T_i - T_a) / I \right)$ was used to normalize the effect of operating at different values of I , T_i and T_a . The results are found in Figures 2 and 3.

The result of second order polynomial analysis is shown in Figures 2 and 3. The second order polynomial to best describe the test results is:

$$\text{Efficiency} = a_0 + a_1 x + a_2 x^2$$

7.0

ANALYSIS (Continued)

7.1

Thermal Performance Test (Continued)

where:

$$T = (t_i - t_a) T$$

and the coefficients are determined to be:

Flow Rate (Lbm/hr)	380	680
a ₀	56.98	59.71
a ₁	-59.84	-89.37
a ₂	-64.74	- 7.96

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TABLE I

YING SOLAR COLLECTOR THERMAL EFFICIENCY TEST DATA
WITH FLOW RATE OF 380 LB./HR. WATER/PRESTONE SOLUTION

Test Identification	Flow Rate, GPM	Volumetric Heat, * BTU/lb °F	Ti, °F	Ta, °F	Solar Flux, BTU/Hr·Ft ²	(To-Ti), °F **	(Ti-Ta)/I, °F·Hr·Ft ² /BTU	Efficiency, %	Windspeed, MPH
1	.73	.845	62.1	38.6	298.0	25.5	.079	52.4	NW/9
2	.63	.845	66.8	46.4	322.4	32.3	.063	52.9	NW/9
3	.73	.860	94.8	45.7	315.0	21.4	.155	49.2	NW/5
4	.73	.860	102.8	51.6	322.2	21.8	.158	43.2	SW/2
5	.73	.865	121.8	50.5	335.0	20.5	.213	38.4	SW/5
6	.73	.865	122.0	50.5	329.9	21.7	.216	40.9	S/2
7	.73	.868	132.0	34.7	330.8	17.5	.294	33.2	S/5
8	.73	.870	145.0	49.0	323.0	19.0	.295	37.1	SW/4
9	.72	.876	184.4	32.6	354.5	11.1	.429	19.6	SW/2
10	.72	.876	187.4	34.4	353.0	10.2	.433	18.1	SW/2

* Volumetric Heat = (Specific Heat) · (Specific Gravity)

** To = T_{f,e} = Temperature of the transfer fluid leaving the collector. (A)

TABLE II
YING SOLAR COLLECTOR THE THERMAL EFFICIENCY TEST DATA
WITH FLOW RATE OF 680 LB./HR. WATER/PRESTONE SOLUTION

Test Identification	Flow Rate, GPM	Volumetric Heat, * BTU/lb °F	Ti, °F	Ta, °F	Solar Flux, BTU/Hr·Ft ²	(To-Ti), °F **	(Ti-Ta)/T _{f,e} - t ₂ /BTU °F·Hr	Efficiency, %	Windspeed, MP
1	1.3	.843	62.0	37.4	289.4	13.7	.085	51.4	NW/9
2	1.3	.843	65.6	45.9	313.6	15.4	.063	53.4	NW/9
3	1.3	.860	89.8	44.3	326.2	14.3	.139	48.7	NW/9
4	1.3	.860	93.0	45.3	328.4	13.5	.145	45.6	NW/9
5	1.3	.860	93.5	46.2	304.8	12.8	.155	46.6	SW/3
6	1.3	.860	99.6	51.3	319.4	13.2	.151	45.8	S/4
7	1.3	.865	122.3	47.0	327.2	11.0	.230	37.5	SE/2
8	1.3	.865	120.5	51.6	331.0	12.7	.208	42.8	SE/3
9	1.3	.868	132.5	33.8	307.9	8.5	.320	30.9	S/0
10	1.3	.875	149.6	52.5	305.9	8.0	.317	29.5	S/3
11	1.3	.876	191.2	35.7	337.0	5.4	.461	18.1	NW/4
12	1.3	.876	191.2	33.6	350.0	7.0	.450	20.5	NW/4

*Volumetric Heat = (Specific Heat) · (Specific Gravity)

**To = T_{f,e} = Temperature of the transfer fluid leaving the collector.

(A)

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- - Platinum Resistance Thermometer
- - Thermocouple Type T
- ◇ - Solar Flux (total PSP)
- △ - Flowmeter
- ✂ - Wind Velocity

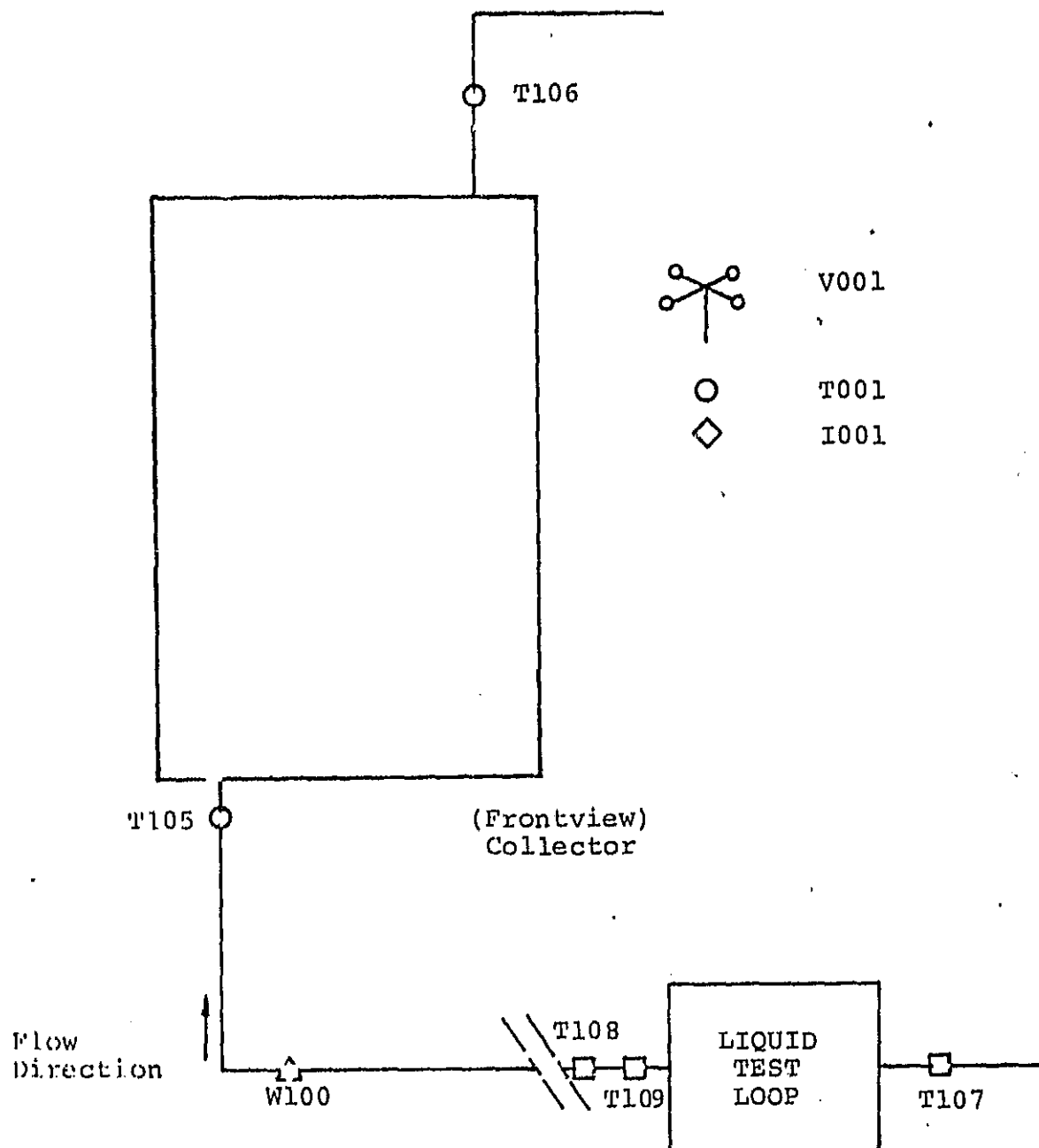


Figure 1. Instrumentation Locations for Ying Collector Test

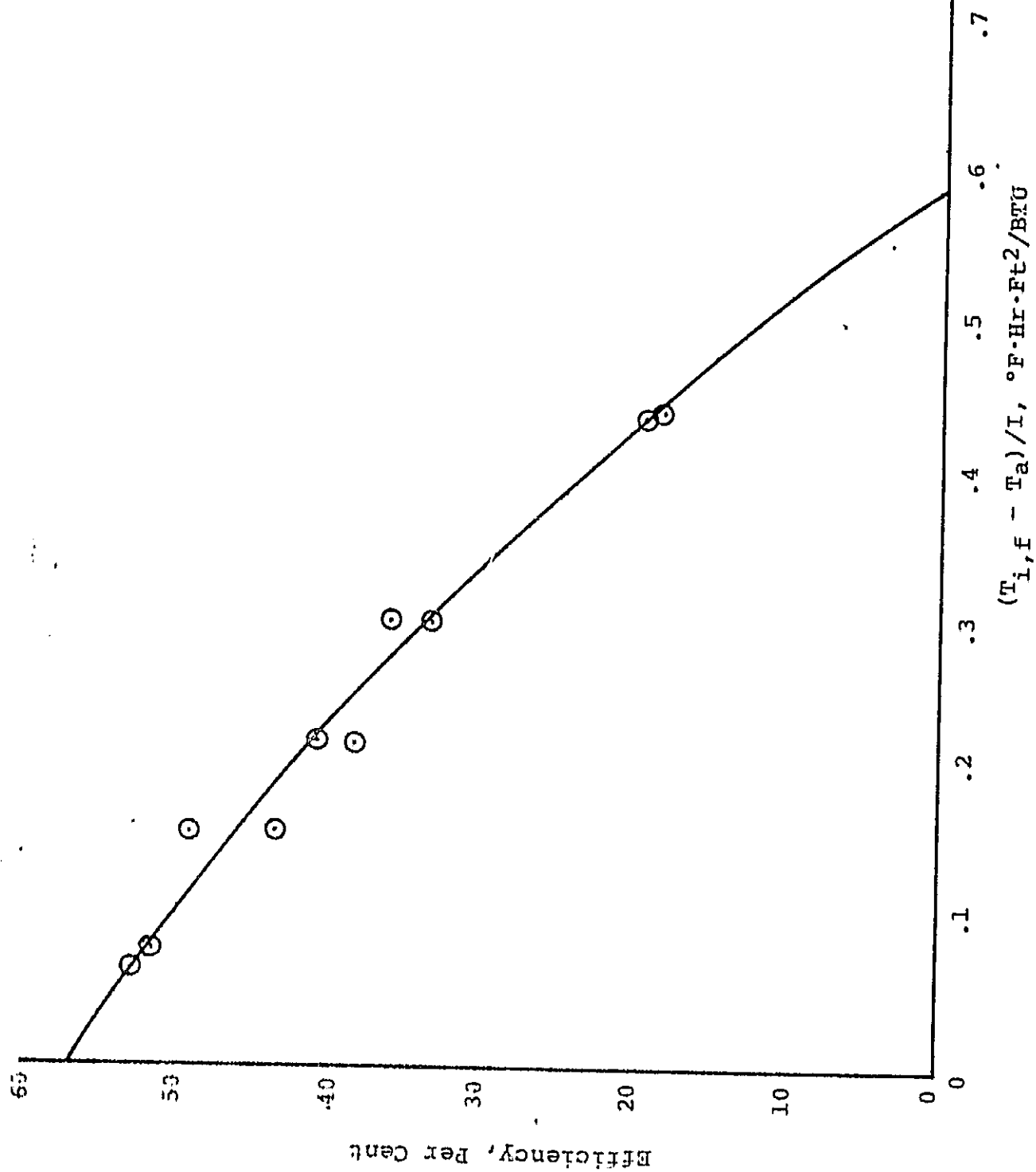
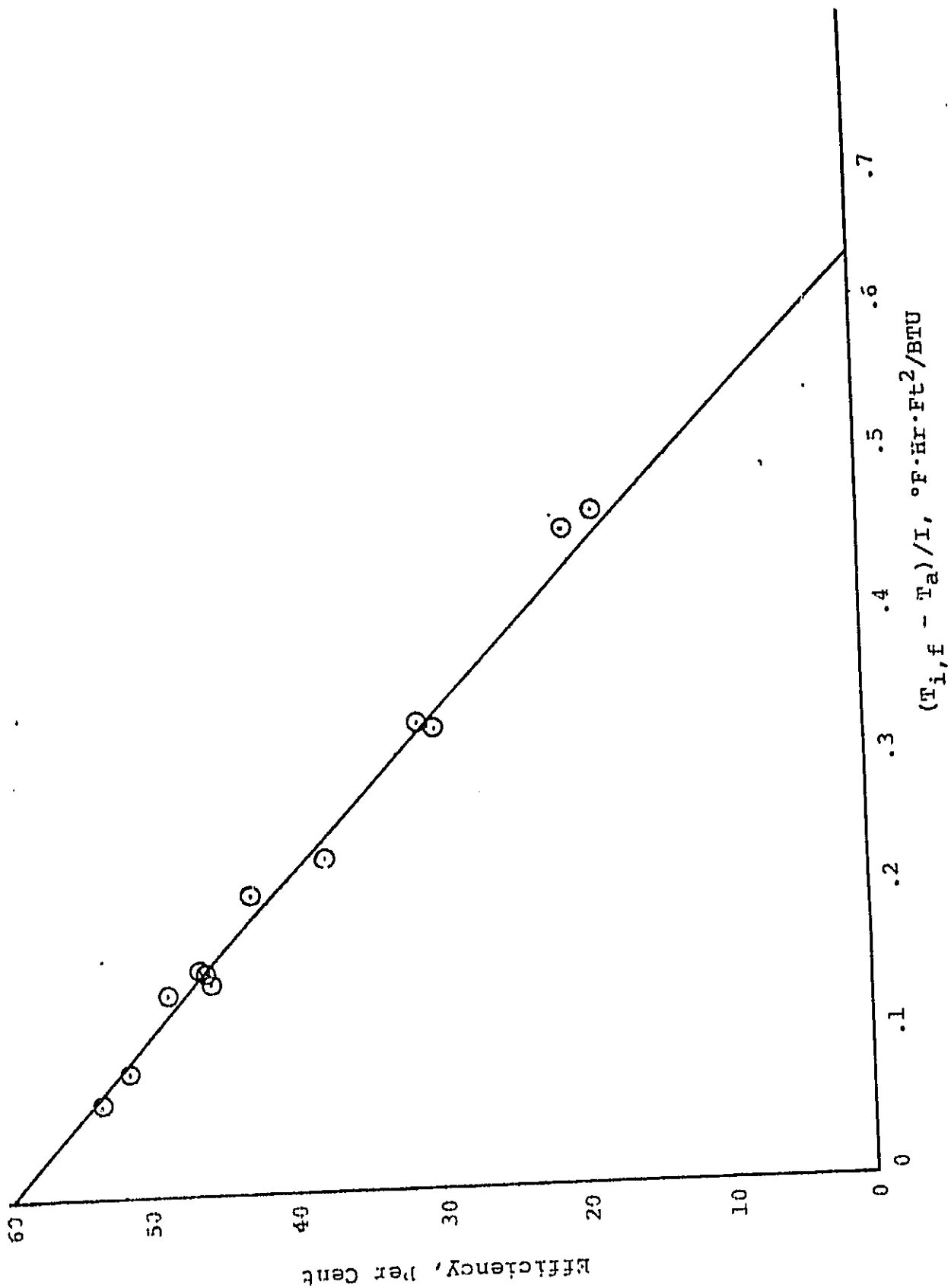


Figure 2. Thermal Efficiency of Ying Collector with 380 lb/hr Flowrate



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Figure 3. Thermal Efficiency of Ying Collector with 680 lb/hr Flowrate